First-pass design for a light, home-brew off-axis 4m dish

Paul Stankus

ORNL

4 Feb 2016

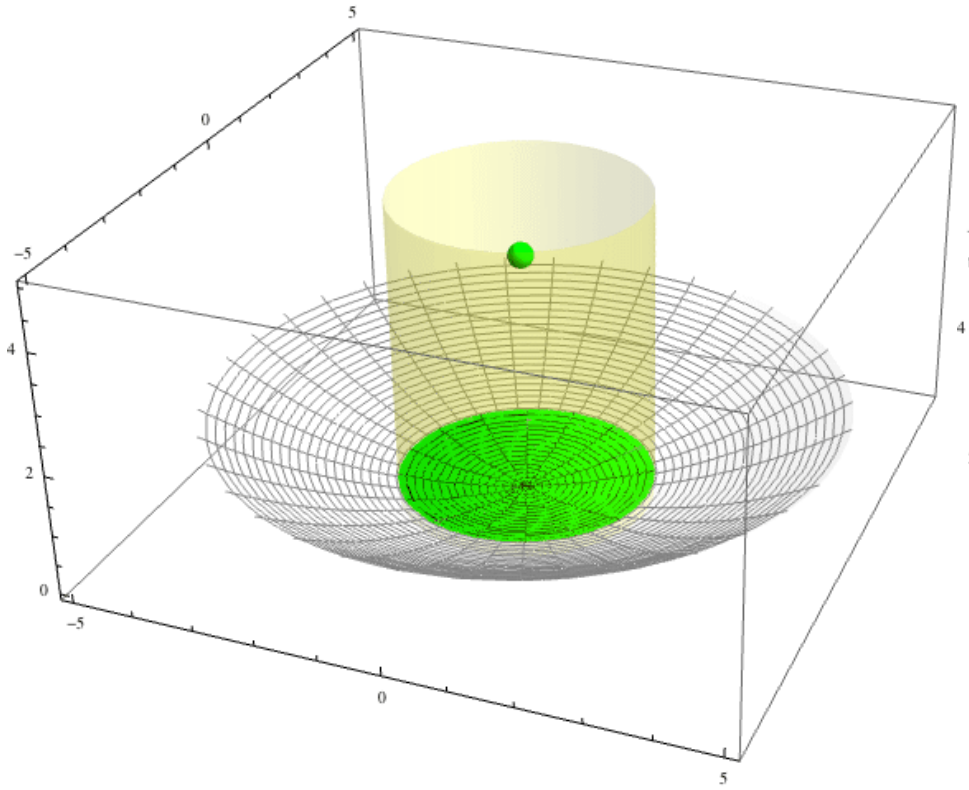
Starting points

Goals:
Inexpensive
Lightweight
Corrosion resistant
Uniform thermal expansion
Easy to machine & assemble
-> all-Aluminum

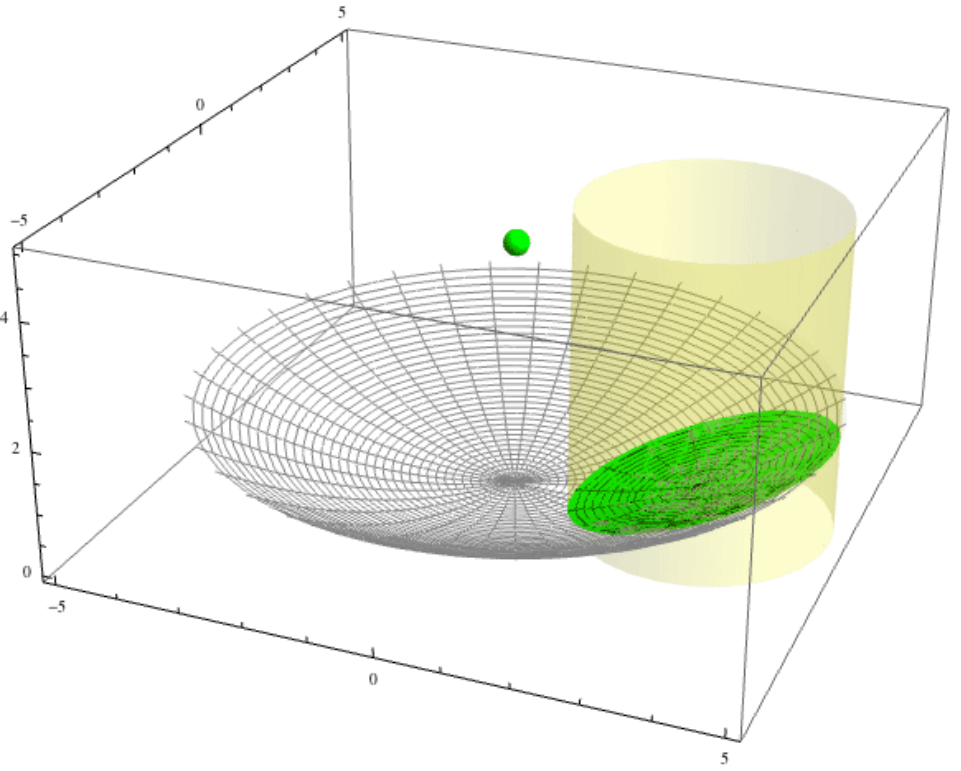
Specs:
Aperture 4m at f/1.0
Reasonably round beam
Off-axis, clearance ~1m
Path-length tolerance ~1cm

Scientific tourism
Arecibo, April 2012

Paraboloids for beginners

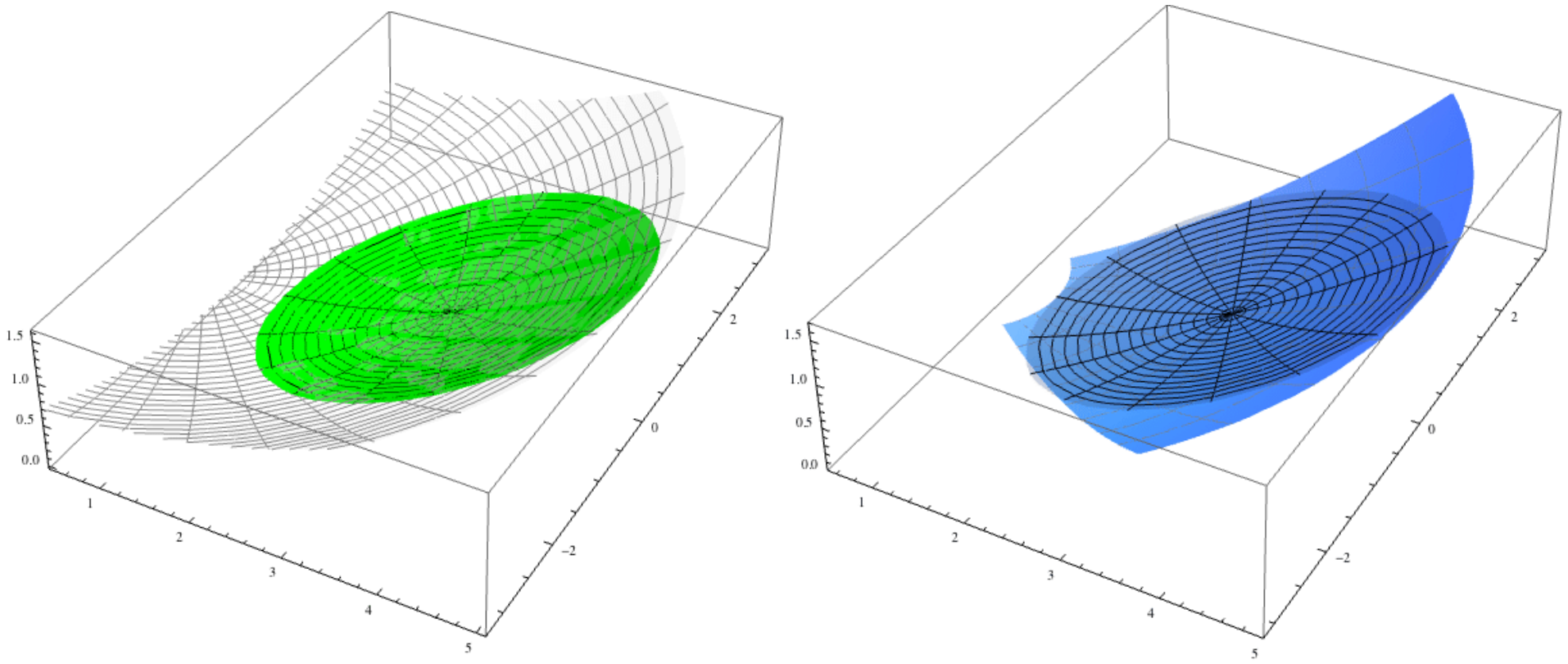


On-Axis: highly symmetric dish partially blocked by focus detector and supports



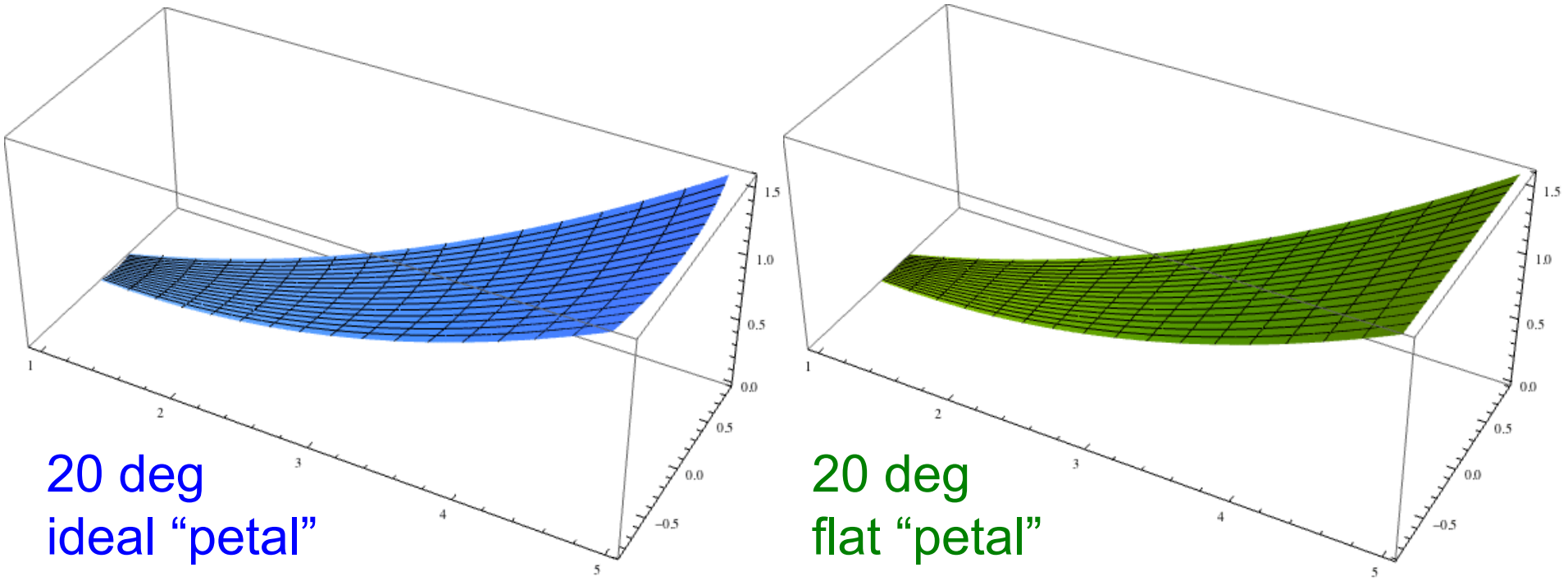
Off-Axis: less symmetric dish; will assume for now that beam direction is vertical

Friendly symmetry



Can cover area of 4m diameter, 1m off-axis beam with a rotationally symmetric segment, R = 1—5m and about 80 degrees in azimuth; allows for repeated “flower petal” approach to construction.

The “flat petal” approximation



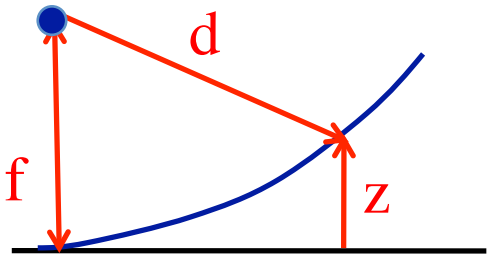
20 deg
ideal “petal”

20 deg
flat “petal”

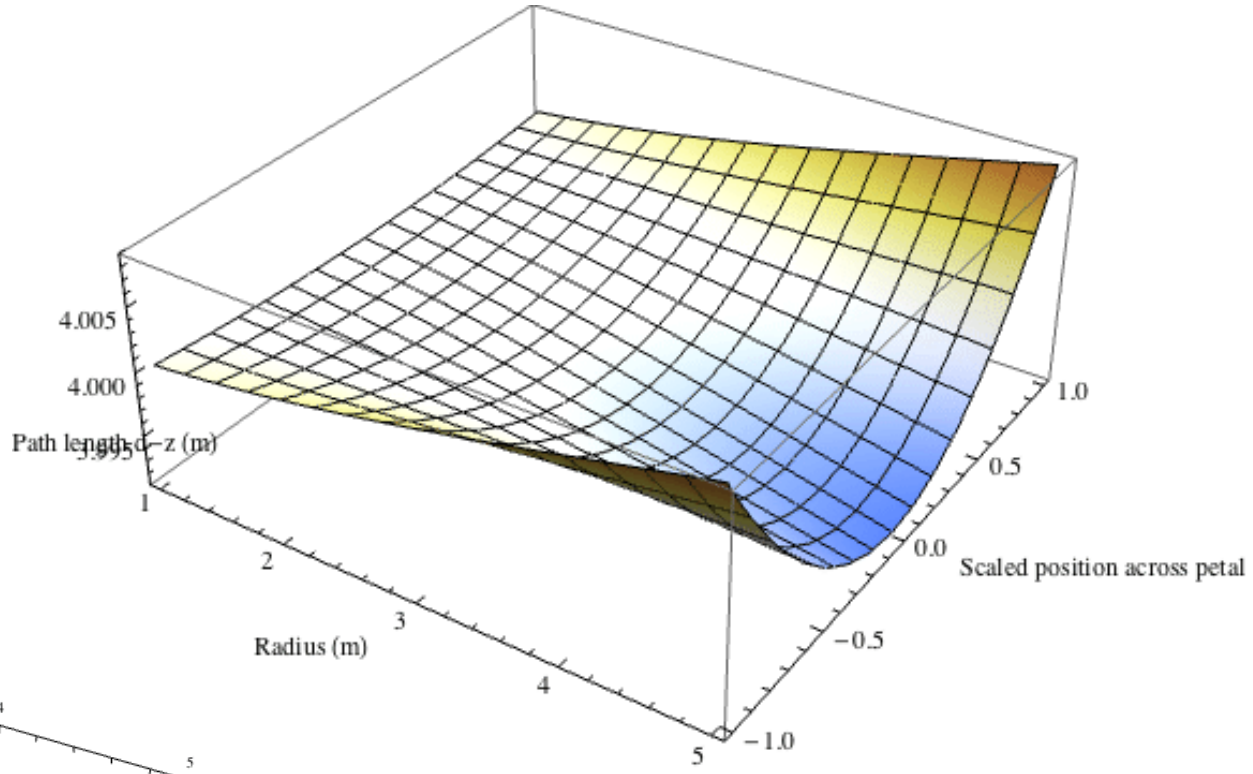
We want to **unroll** the reflector material with curvature in only one direction, **not hammer** it into a bowl with curvature in two directions.

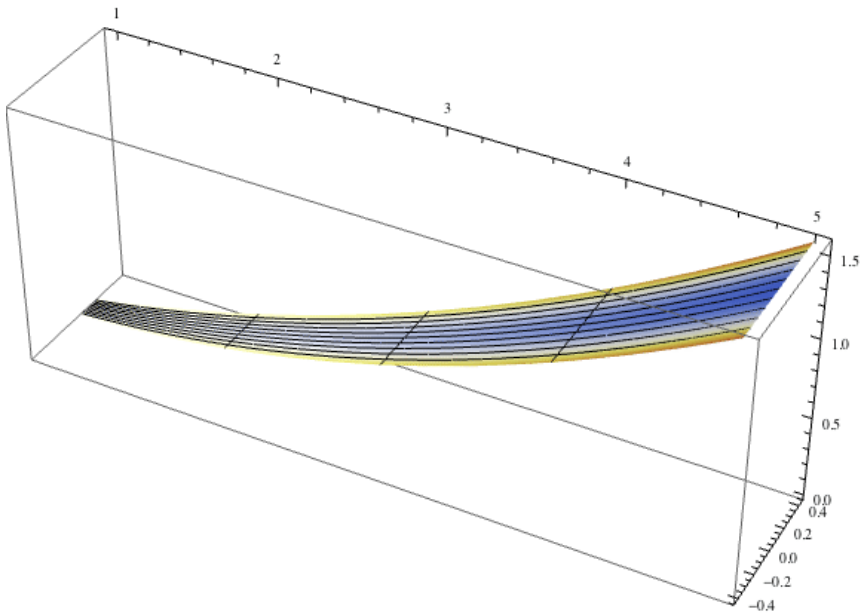
Q: How large a petal, in angle, can we tolerate at this radius?

Path length figure of merit



For a perfect paraboloid, d-z = f is constant over the surface





We can measure d-z over our flat petal, and see that for a 10-degree width the path length defect is everywhere less than +/- 1cm.

Two reflector rules of thumb:

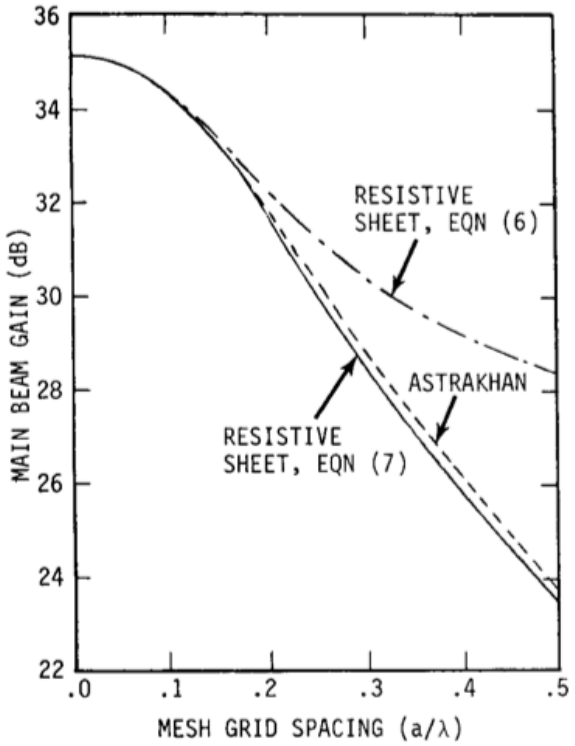


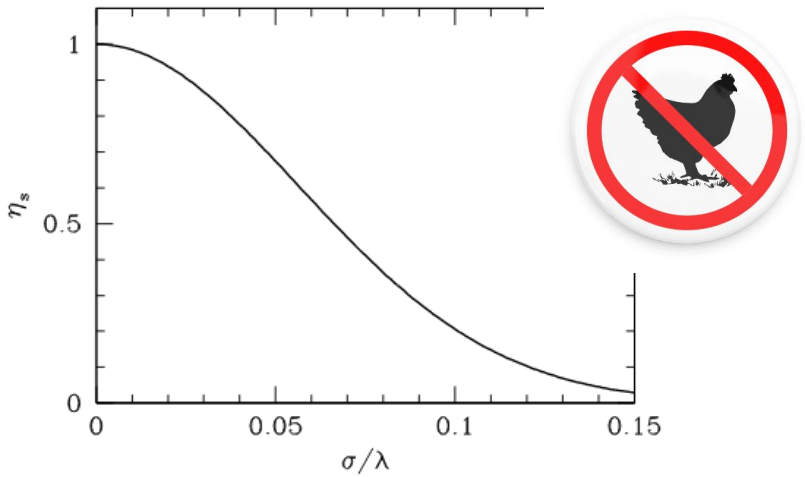
Fig. 3. Gain of a 20λ paraboloid as a function of mesh grid size. (f/D = 0.4, cos θ feed, $r_0 = 0.002\,\lambda$.)

Grid spacing < 0.1 λ

IEEE Trans. Ant. Prop. vol37 No11 1989

$$\eta_s = \exp\left[-\left(\frac{4\pi\sigma}{\lambda}\right)^2\right]$$

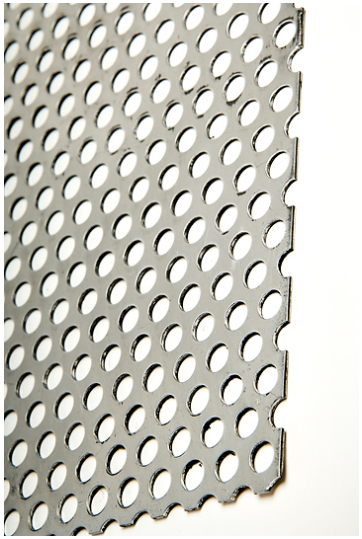
This is often called the ***Ruze equation***.

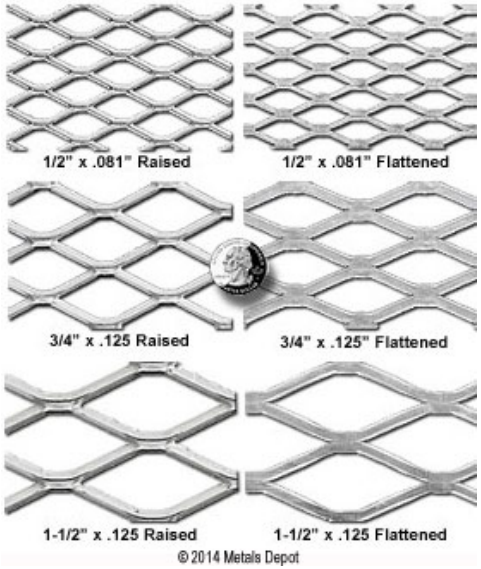


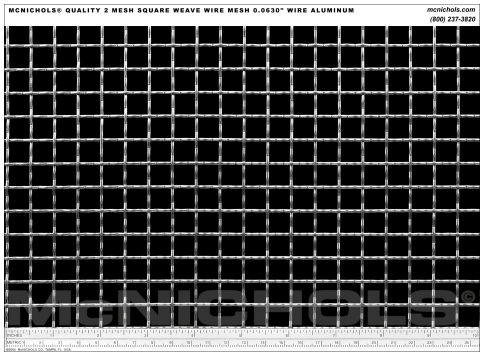
Flatness variation < 0.05 λ

www.cv.nrao.edu/course/astr534/2DApertures.html

What can we unroll or flex a bit?



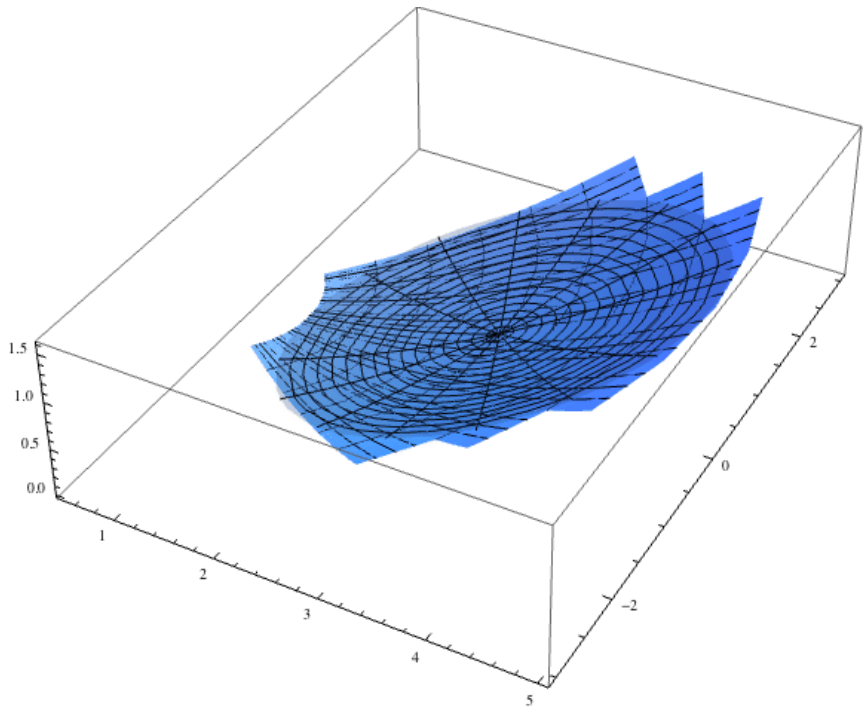


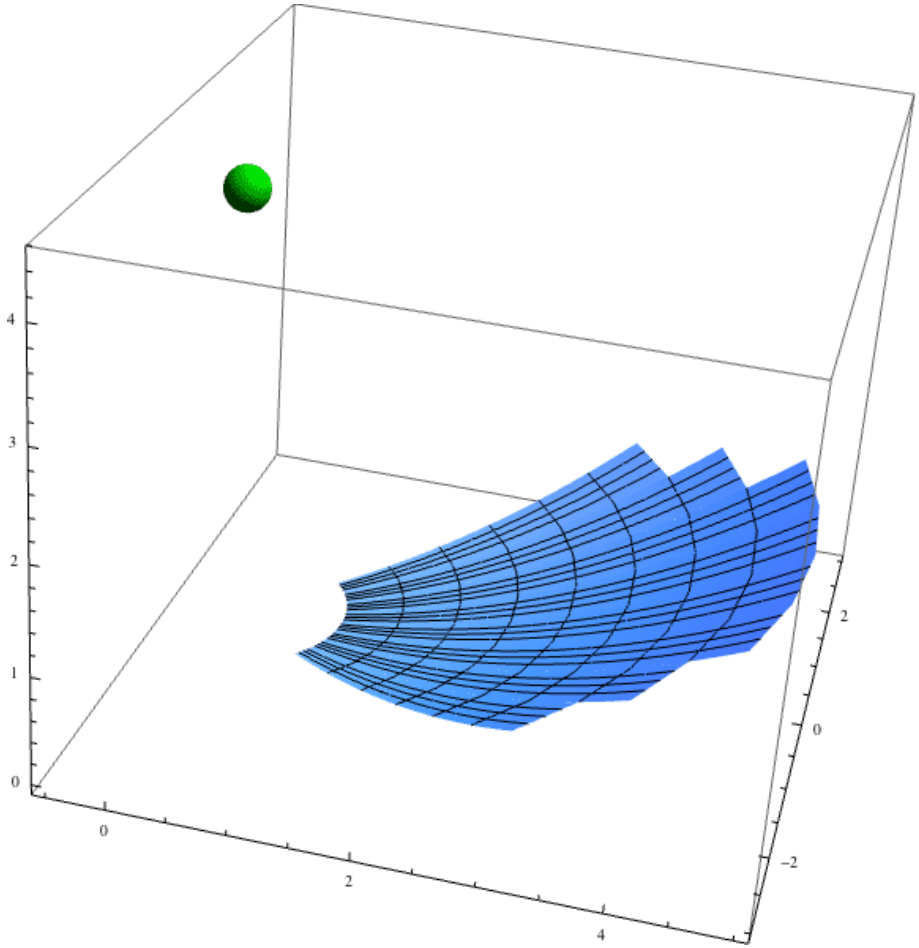


Perforated Al sheet 3/64”~1mm thick	Expanded Al sheet 0.081” thick	Al wire mesh 0.063” strand	Hardware cloth (galv. steel 0.25”)
$50/m^2$	$45/m^2$	$25/m^2$	$9/m^2$
0.40 lb/ft^2	0.45 lb/ft^2	0.18 lb/ft^2	0.16 lb/ft^2
Added structural strength; best ground shield; solar concentrator (!)	Some structural strength, inexact attachments	Little structural strength, hard to keep flat	Very cheap; may be hard to keep flat; differing thermal expansion

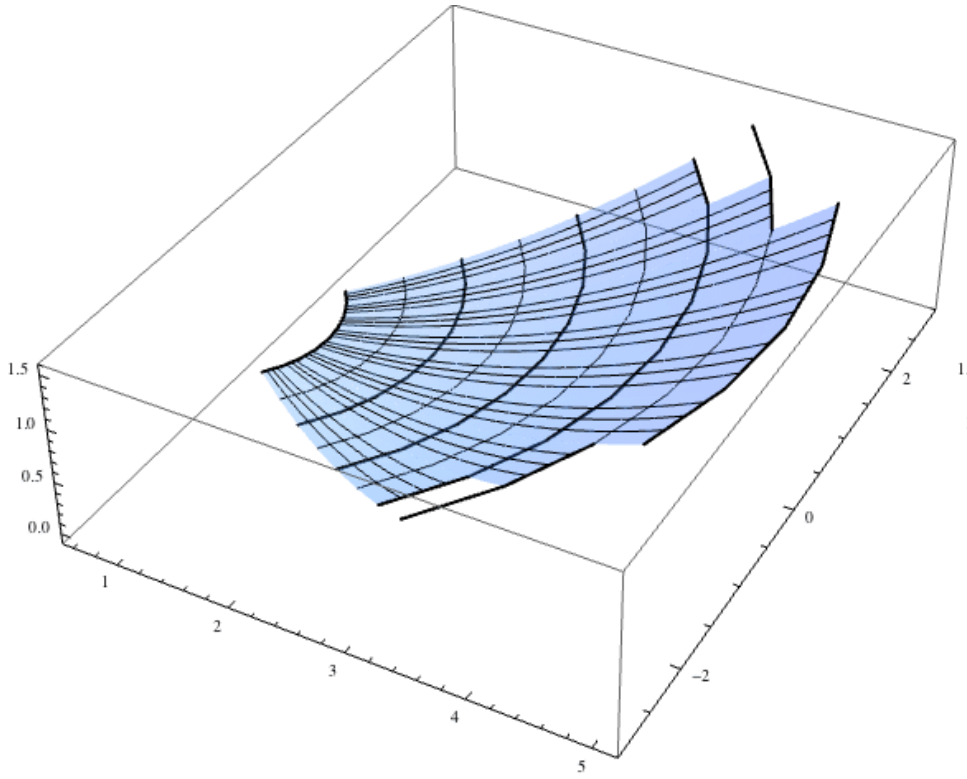
Full flat-petal coverage

We can cover the nominal round beam quite nicely using eight 10-degree flat petals at 3.0m, 3.5m and 4.0m lengths

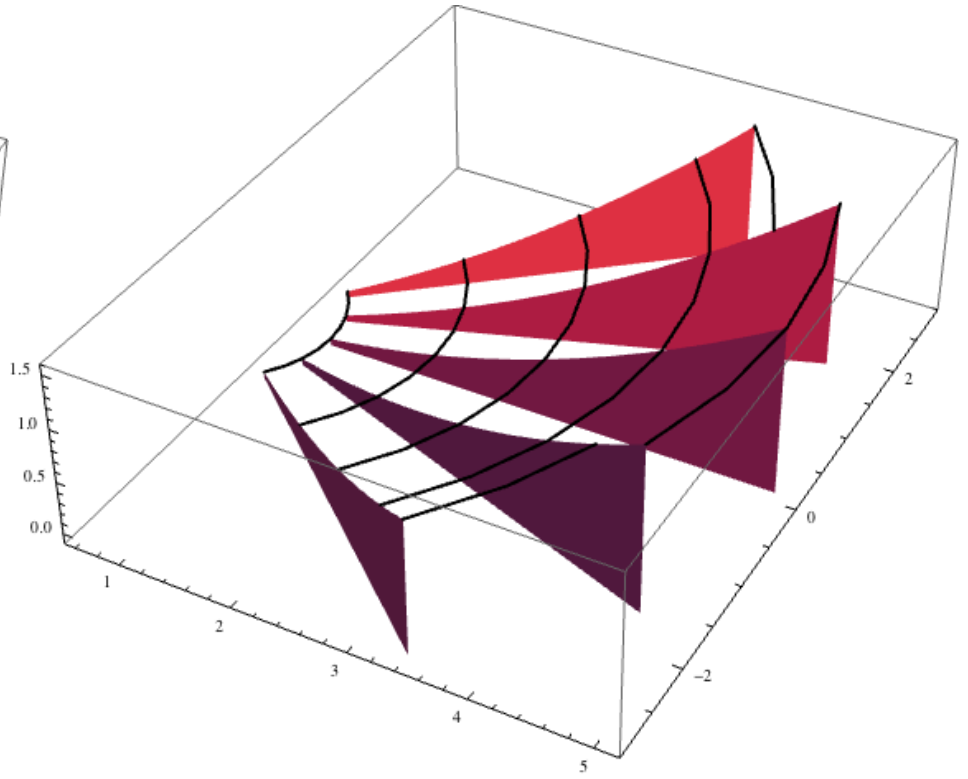




Structural support 1: cross bars

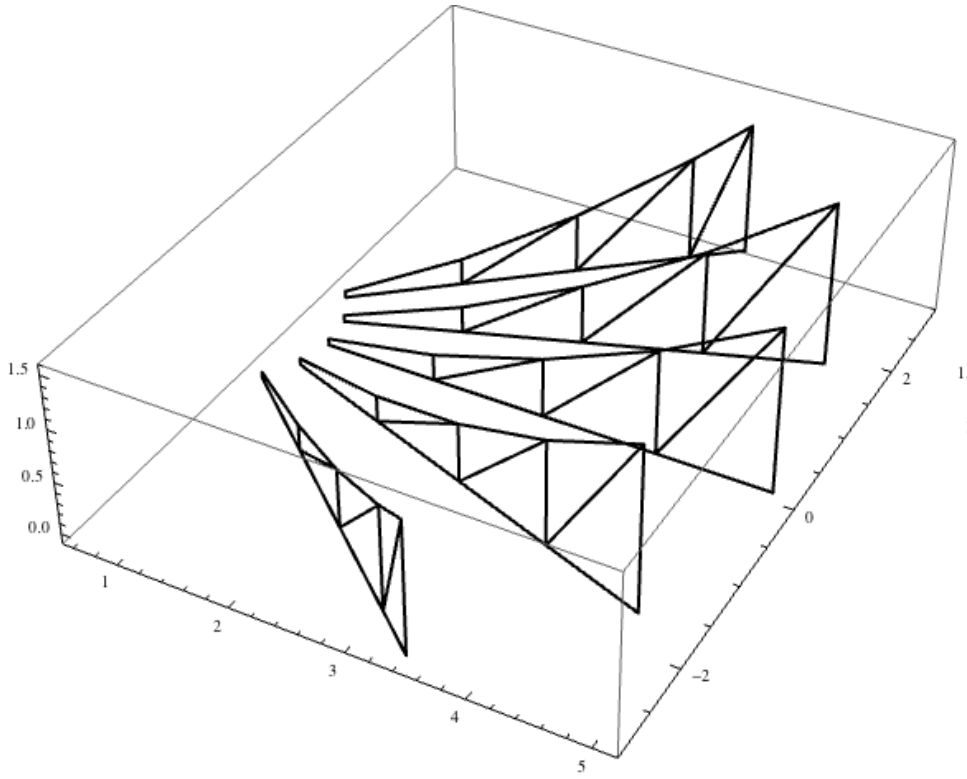


The gently curving flat petals are supported on cross-bars, here spaced every ~1m; presumably fine-tuned with screw stems for final alignment.

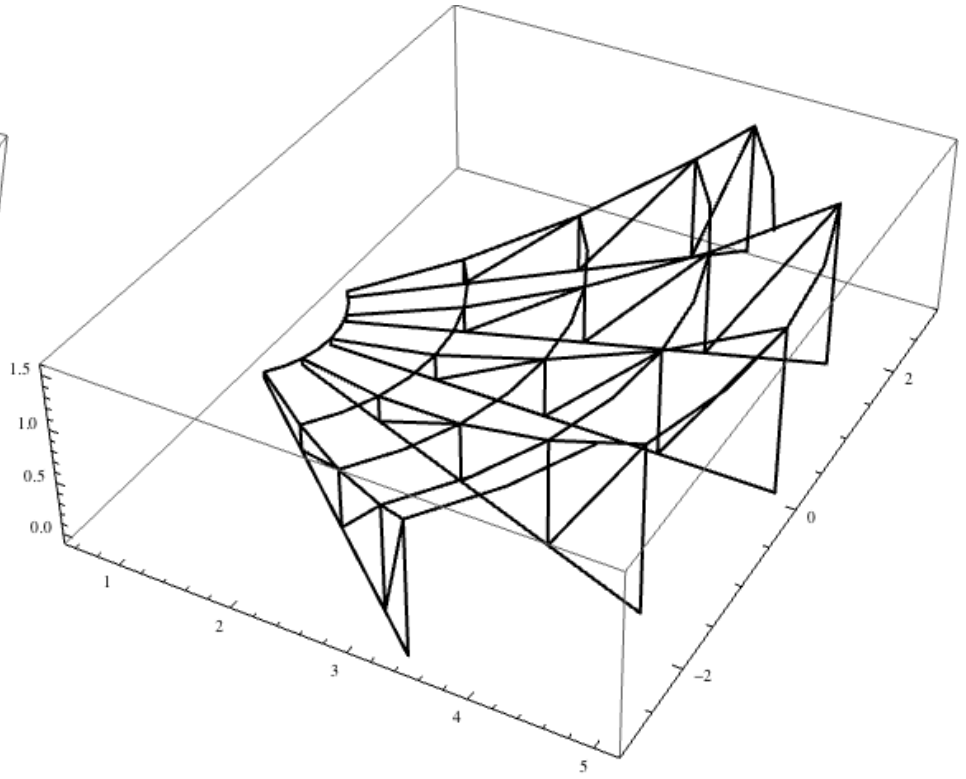


The cross-bars can be supported in any number of ways; effectively a truss web shown here, spaced one per two 10-degree petals.

Structural support 2: trusses

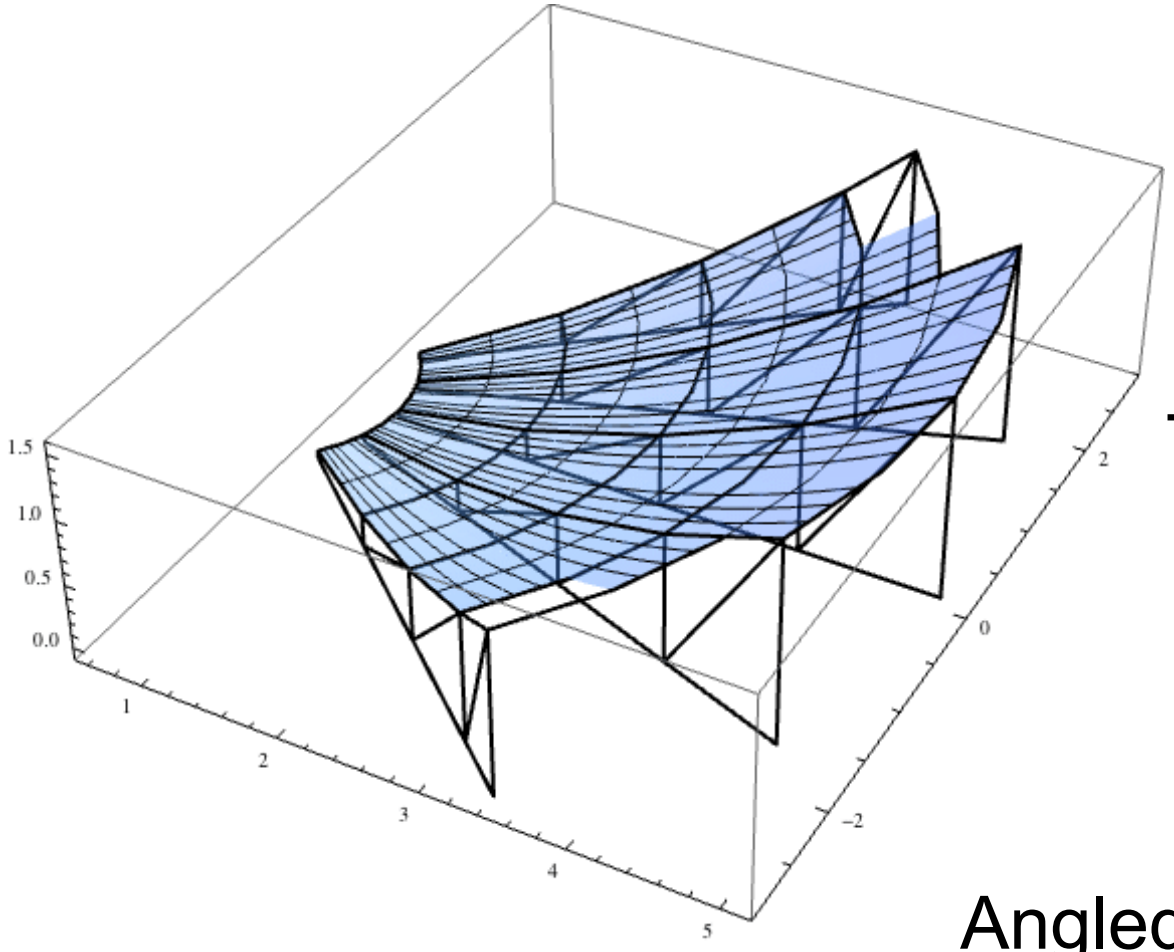


The lightest solution for supporting an extended length will always be a truss of some kind; many options are possible; truss planes are vertical if beam axis is vertical.



Full frame for the flat petals, with crossbars supported by trusses. (Additional box crosses not shown.)

Nominal parts lists



Petal area ~ 14 m^2

Weight 70 – 190 lb

Parts cost $150 – $700

Truss and crossbars

Total length ~ 350 ft

Al bar 1/8” x 3/4”

Weight ~35-50+ lb

Parts cost $200 – $300

Angled joints at crossbars

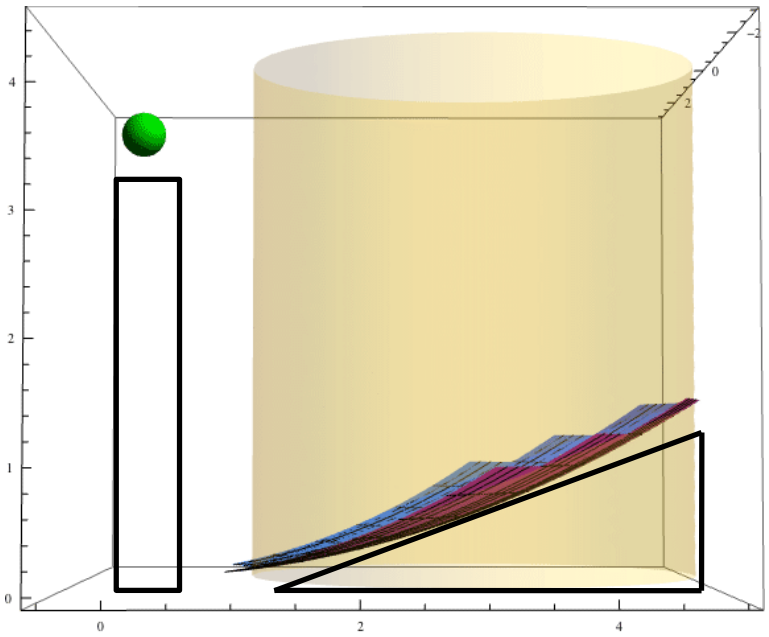
3-D printed precision non-flat wedge washers, ~x100 (free?)

Summary thoughts

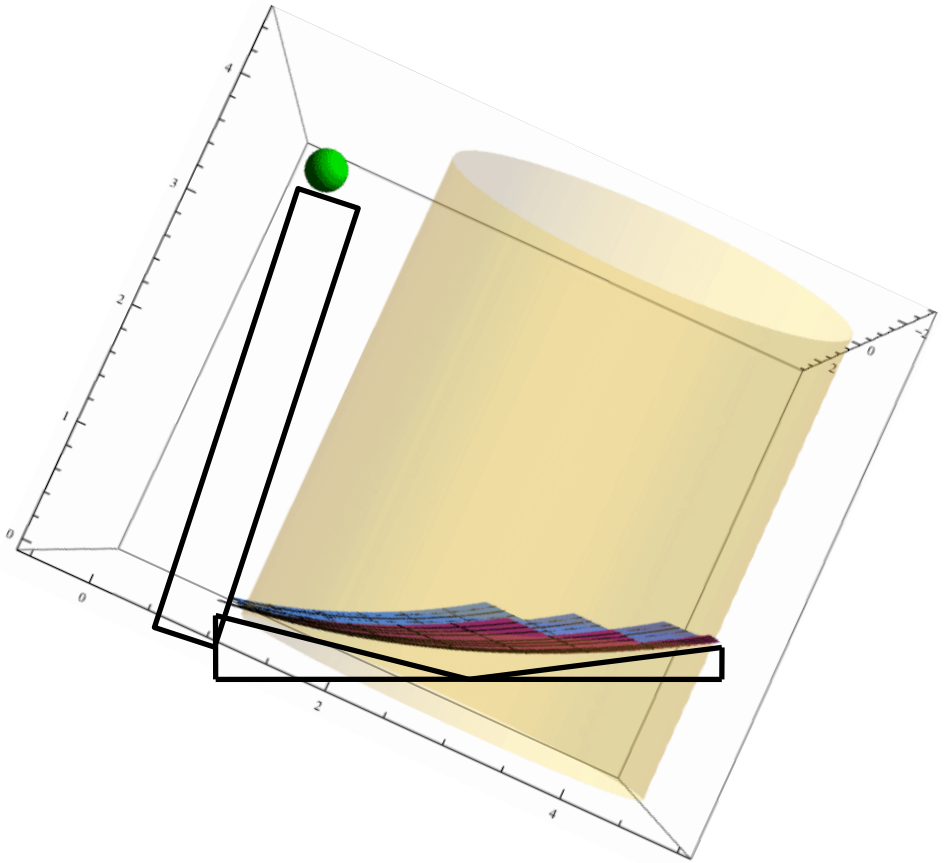
- It should be possible to build a very light (100-200 lb) dish satisfying: 4m diameter, round beam, off-axis, f/1.0, ~1cm flatness/path length
- Parts cost is trivial on LDRD scale $\$10^3 << \$10^5$, and much smaller than physicist's time cost
- Should be tilt- and steer-able to at least 20 degrees from zenith; need to integrate with interface to ground and horn receiver support
- What is the advantage of home-brew over buying from General Dynamics or eBay?
  (1) Gain experience, (2) Naturally extend design for larger instruments, D ~ 10m or 30m

Backup, further notes

Tilt, or whirl?



Building the prototype with a vertical beam is inefficient in terms of the truss, though it is simpler because the truss planes are all vertical; focus support tower can be on a disconnected footprint.



With a beam set at 20deg the dish is much closer to horizontal, the truss is smaller, and the focus is over the dish.

Fixed tilt beam can still scan the sky if the assembly rotates around the vertical.

Environmental factors

- On Long Island, need to worry about:
  - High winds (50 mph)
  - Salt air, high humidity
  - Snow loads (15-30 lb/ft^2)
  - Freezing rain and ice accumulation
  - Temperature swings (80 degF = $\Delta l/l \sim 10^{-3}$ for Al)

- Also keep in mind
  - Requirements for technicians and union labor in design, machining, and assembly at BNL